Original Investigation

Concussion Symptoms and Return to Play Time in Youth, High School, and College American Football Athletes

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IMPORTANCE To our knowledge, little research has examined concussion across the youth/adolescent spectrum and even less has examined concussion-related outcomes (ie, symptoms and return to play).

OBJECTIVE To examine and compare sport-related concussion outcomes (symptoms and return to play) in youth, high school, and collegiate football athletes.

DESIGN, SETTING, AND PARTICIPANTS Athletic trainers attended each practice and game during the 2012 to 2014 seasons and reported injuries. For this descriptive, epidemiological study, data were collected from youth, high school, and collegiate football teams, and the analysis of the data was conducted between July 2015 and September 2015. The Youth Football Surveillance System included more than 3000 youth football athletes aged 5 to 14 years from 118 teams, providing 310 team seasons (ie, 1 team providing 1 season of data). The National Athletic Treatment, Injury, and Outcomes Network Program included 96 secondary school football programs, providing 184 team seasons. The National Collegiate Athletic Association Injury Surveillance Program included 34 college football programs, providing 71 team seasons.

MAIN OUTCOMES AND MEASURES We calculated the mean number of symptoms, prevalence of each symptom, and the proportion of patients with concussions that had long return-to-play time (ie, required participation restriction of at least 30 days). Generalized linear models were used to assess differences among competition levels in the mean number of reported symptoms. Logistic regression models estimated the odds of return to play at less than 24 hours and at least 30 days.

RESULTS Overall, 1429 sports-related concussions were reported among youth, high school, and college-level football athletes with a mean (SD) of 5.48 (3.06) symptoms. Across all levels, 15.3% resulted return to play at least 30 days after the concussion and 3.1% resulted in return to play less than 24 hours after the concussion. Compared with youth, a higher number of concussion symptoms were reported in high school athletes (β = 1.39; 95% CI, 0.55-2.24). Compared with college athletes, the odds of return to play at least 30 days after injury were larger in youth athletes (odds ratio, 2.75; 95% CI, 1.10- 6.85) and high school athletes (odds ratio, 2.89; 95% CI, 1.61-5.19). The odds of return to play less than 24 hours after injury were larger in youth athletes than high school athletes (odds ratio, 6.23; 95% CI, 1.02-37.98).

CONCLUSIONS AND RELEVANCE Differences in concussion-related outcomes existed by level of competition and may be attributable to genetic, biologic, and/or developmental differences or level-specific variations in concussion-related policies and protocols, athlete training management, and athlete disclosure. Given the many organizational, social environmental, and policy-related differences at each level of competition that were not measured in this study, further study is warranted to validate our findings.

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In the United States, American football is a popular sport, with approximately 3 million youth, 1.1 million high school, and 100 000 college athletes participating annually.[1-3] Although sports participation provides regular physical activity and is associated with physical, psychological, social, and academic benefits,[4] there remains concern about sport-related concussions. The Centers for Disease Control and Prevention estimates that annually, 1.6 to 3.8 million concussions occur in sports and recreational activities.[5] A concussion typically presents with emotional, cognitive, somatic, and sleep-related symptoms and impairments.[6,7]

A 2013 report by the Institute of Medicine[8] highlighted the need for more extensive concussion data in athletes aged 5 to 21 years, which encompasses youth, high school, and collegiate athletes. High school and collegiate athletes have been well studied in the past decade[9-12]; however, youth sports concussions remain understudied.[13] A 2015 study[14] found that the 1-year concussion risk in youth football was lower than that in high school and college football.

Previous research across all levels of competition has indicated that common self-reported concussion-related symptoms were headache, dizziness, and confusion.[15-21] Surveillance data of high school athletes showed that 23% of concussions resulted in return to play within 1 week of injury,[12] compared with 37% of collegiate athletes.[9] Research suggests that high school athletes may take longer to recover after concussion both symptomatically and on neurocognitive testing.[22-24] However, there is a lack of related research in youth athletes, although puberty and brain development may affect concussion-related outcomes.[25,26] Therefore, the purpose of this study was to examine sport-related concussion outcomes, including symptoms and return to play, in youth, high school, and collegiate football athletes.

Key Points

Question How do concussion outcomes differ among youth, high school, and college football athletes?

Findings In this descriptive, epidemiological study of 1429 sports-related concussions, concussions in high school football had the highest mean number of reported symptoms, followed by college and youth. The proportion of concussions with return-to-play time of at least 30 days was the highest in high school athletes, followed by youth and college athletes.

Meaning There are differences in concussion outcomes across levels of competition in football, which could be attributed to biologic differences or organizational, social-environmental, and policy-related differences.

Methods

Data were collected as part of 3 injury surveillance programs: (1) the Youth Football Safety Study; (2) the National Athletic Treatment, Injury, and Outcomes Network; and (3) the National Collegiate Athletic Association (NCAA) Injury Surveillance Program. The Youth Football Safety Study included youth football athletes aged 5 to 14 years from 118 teams, providing 310 team seasons (ie, 1 team providing 1 season of data). The National Athletic Treatment, Injury, and Outcomes Network program included 96 secondary school football programs, providing 184 team seasons.[27] The NCAA Injury Surveillance Program included 34 college football programs, providing 71 team seasons.[28] The Youth Football Safety Study and National Athletic Treatment, Injury, and Outcomes Network protocols were approved by Western Institutional Review Board (Puyallup, Washington) and the NCAA Injury Surveillance Program protocol was approved by the NCAA Research Review Board (Indianapolis, Indiana). Patient consent was not obtained because all 3 surveillance studies were deemed exempt.

Protocol

At all 3 levels of competition, at least 1 athletic trainer attended each practice and game during the 2012 to 2014 seasons and reported concussion and exposure data via their preferred injury documentation application. Athletic trainers completed a detailed report on the injury circumstances such as event type (ie, competition or practice). Injury documentation applications worked with Datalys to ensure that data were collected in similar manners across systems and levels of competition (Datalys Center Inc).

A reportable injury in all 3 surveillance programs was an injury occurring as a result of participation in an organized practice/game and requiring attention from an athletic trainer or physician. We did not provide a definition of concussion because we relied on the medical expertise of the athletic trainer or physician providing data, although they were encouraged to follow the definition provided by the Consensus Statement on Concussion in Sport.[7] All concussions were assessed by athletic trainers and/or physicians. At the youth level, all concussions were required to have physician clearance to return to play following concussion. At the high school level, concussion management was determined locally by the institution or state guidelines. At the collegiate level, NCAA legislation passed in 2010 required approval from a physician and/or physician designee before returning an athlete to play.

For all levels, when a concussion occurred, student athletes reported symptoms associated with the concussion. For youth athletes, information from both the parents/guardians and the athletes were used to determine concussion symptoms; this may have required athletic trainers to follow up with parents/guardians. Symptoms were selected from a 17-item yes/no checklist. In grouping symptoms, we used a modification of the Lau et al[20] symptom clusters (cognitive, migraine, neuropsychiatric, and sleep). The migraine cluster included headache, dizziness, sensitivity to light/noise, nausea/vomiting, tinnitus, loss of balance, and visual disturbance. The cognitive cluster included posttraumatic amnesia, retrograde amnesia, difficulty concentrating, disorientation, loss of consciousness, and excess drowsiness. The neuropsychiatric cluster included excessive excitability and irritability. The sleep cluster included insomnia. After initially inputting injury data, athletic trainers could return to update symptoms, such as delayed onset of symptoms, as needed. Thus, our symptom measure is an aggregate of symptoms reported at any point during recovery.

Table 1. Team Seasons,[a] Concussion Counts, and Rates in Youth, High School, and College Football, 2012 to 2014 Seasons[b]

Level of Play	No. of Team Seasons	Game		Practice	
		No. of Concussions	Injury Rate Per 1000 Athlete Exposures (95% CI)	No. of Concussions	Injury Rate Per 1000 Athlete Exposures (95% CI)
Youth	310	95	2.13 (1.70-2.56)	87	0.53 (0.42-0.64)
High school	184	357	1.61 (1.45-1.78)	478	0.47 (0.43-0.51)
College	71	183	3.52 (3.01-4.03)	229	0.47 (0.41-0.53)
Total	565	635	2.00 (1.84-2.15)	794	0.48 (0.44-0.51)

[a] One team's participation in 1 season.

[b] Data originate from the Youth Football Surveillance System for youth; National Athletic Treatment, Injury, and Outcomes Network for high school; and National Collegiate Athletic Association Injury Surveillance Program for college, 2012 to 2014 seasons.

Table 2. Mean, Median, and Distribution of Number of Symptoms Reported by Athletes With Concussions in Youth, High School, and College Football, 2012 to 2014 Seasons[a]

Statistic	Level of Competition			
	Youth	High School	College	Total
Mean (SD)	4.76 (2.58)	5.60 (3.16)	5.56 (3.03)	5.48 (3.06)
Median (25th-75th percentile)	4 (3-7)	5 (3-8)	5 (3-8)	5 (3-8)
Distribution, No. (%)				
<4	64 (36.2)	241 (29.2)	117 (28.4)	422 (29.9)
4 to 6	68 (38.4)	273 (33.1)	143 (34.8)	484 (34.3)
7 to 9	34 (19.2)	216 (26.2)	101 (24.6)	351 (24.9)
10 to 12	11 (6.2)	77 (9.3)	43 (10.5)	131 (9.3)
≥13	0 (0.0)	18 (2.2)	6 (1.4)	24 (1.7)
Missing	5	10	2	17

[a] Symptoms represent those reported to medical staff at any point during recovery. Data originate from the Youth Football Surveillance System for youth; National Athletic Treatment, Injury, and Outcomes Network for high school; and National Collegiate Athletic Association Injury Surveillance Program for college, 2012 to 2014 seasons.

Athletic trainers selected from a categorical variable for return-to-play time (ie, the time required for full return to sports participation). Return-to-play time was categorized as less than 24 hours, 24 hours to 6 days, 7 to 13 days, 14 to 29 days, and 30 or more days. Concussions that resulted in a long time to return to play were those requiring at least 30 days before return to play or resulting in the athletes prematurely ending their season.

From the electronic health record applications, common data elements that included injury and exposure information were stripped of any personally identifiable information.[28] This common data element standard allowed the athletic trainers to document injuries as they normally would as part of their daily clinical practice. All electronic health record applications must have successfully completed a data-validation process to be certified. All 3 programs used the same technology, method, and common data elements with slight variations accommodating for setting and level of competition.[27,28]

Exported data passed through an automated verification process that conducted a series of consistency checks. Data were reviewed and flagged for invalid values. The athletic trainer and data quality assurance staff were notified and worked together to resolve the issue. Data that passed the verification process were then placed into the aggregate data sets.

Statistical Analyses

Data were analyzed to assess patterns of concussion outcomes sustained in all 3 levels of football. Our 3 outcomes were the mean number of reported symptoms, the prevalence of each symptom, and return-to-play time. The mean number of symptoms presenting with concussions were calculated for all symptoms and the Lau et al[20] symptom clusters. Cases with missing outcome data were excluded from analyses.

To account for clustering within league in youth football and within team in high school and college football, generalized estimating equations with an exchangeable covariance structure were used for all analyses. Clusters (league or team) were based on the level at which each athletic trainer covered football. Generalized linear models (identity link and normal distribution) were used to assess differences among competition levels in the mean number of reported symptoms overall and within the Lau et al[20] symptom clusters. Generalized linear models (logit link and binary distribution) estimated the odds of return to play at less than 24 hours and at 30 days or more. Bonferroni corrections accounted for the 3 comparisons conducted for each outcome (youth vs high school; youth vs college; and high school vs college). Data were analyzed using SAS-Enterprise Guide software, version 5.1 (SAS Institute Inc).

Results

Overall Findings

During the 2012 to 2014 seasons, a total of 1429 concussions were reported across all 3 levels of competition (**Table 1**). A mean (SD) of 5.48 (3.06) symptoms were reported across all concussions (**Table 2**). In addition, a mean (SD) of 1.51 (1.29) cognitive symptoms and 3.57 (1.88) migraine symptoms were reported. The most commonly reported symptoms were headache (n=1331 [94.3%]), dizziness (n=1059 [75.0%]), and difficulty concentrating (n=854 [60.5%]; **Table 3**). In addition, 219

Table 3. Symptoms Reported by Athletes With Concussions in Youth, High School, and College Football, 2012 to 2014 Seasons

Symptom Prevalence[a]	Athletes With Concussions Reporting Symptoms, No. (%)			
	Youth (n = 177)	High School (n = 825)	College (n = 410)	Total (n = 1412)
Migraine				
Dizziness	141 (79.7)	633 (76.7)	285 (69.5)	1059 (75.0)
Headache	175 (98.9)	784 (95.0)	372 (90.7)	1331 (94.3)
Nausea/vomiting	63 (35.6)	285 (34.5)	108 (26.3)	456 (32.3)
Tinnitus	26 (14.7)	85 (10.3)	25 (6.1)	136 (9.6)
Loss of balance	58 (32.8)	285 (34.5)	185 (45.1)	528 (37.4)
Visual disturbances	37 (20.9)	189 (22.9)	133 (32.4)	359 (25.4)
Sensitivity to light	56 (31.6)	409 (49.6)	208 (50.7)	673 (47.7)
Sensitivity to noise	35 (19.8)	325 (39.4)	130 (31.7)	490 (34.7)
Cognitive				
Posttraumatic amnesia	18 (10.2)	104 (12.6)	61 (14.9)	183 (13.0)
Retrograde amnesia	6 (3.4)	69 (8.4)	52 (12.7)	127 (9.0)
Difficulty concentrating	96 (54.2)	512 (62.1)	246 (60.0)	854 (60.5)
Disorientation	63 (35.6)	227 (27.5)	169 (41.2)	459 (32.5)
Loss of consciousness	3 (1.7)	30 (3.6)	20 (4.9)	53 (3.8)
Excess drowsiness	41 (23.2)	298 (36.1)	112 (27.3)	451 (31.9)
Neuropsychiatric				
Excess excitably	7 (4.0)	57 (6.9)	17 (4.1)	81 (5.7)
Excess irritability	15 (8.5)	144 (17.5)	54 (13.2)	213 (15.1)
Sleep				
Insomnia	3 (1.7)	187 (22.7)	101 (24.6)	291 (20.6)

[a] Symptoms represent those reported to medical staff at any point during recovery. Cases with missing data are not included in calculations of percentages (youth, n = 5, high school, n = 10; and college, n = 2). Data originate from the Youth Football Surveillance System for youth; National Athletic Treatment, Injury, and Outcomes Network for high school; and National Collegiate Athletic Association Injury Surveillance Program for college, 2012 to 2014 seasons.

Table 4. Return-to-Play Time for Athletes With Concussions in Youth, High School, and College Football, 2012 to 2014 Seasons

Return-to-Play Time[a]	Level of Competition, No. (%)			
	Youth	High School	College	Total
Less than 24 h	18 (10.1)	7 (0.8)	19 (4.7)	44 (3.1)
1 to 6 d	52 (29.2)	86 (10.4)	105 (26.2)	243 (17.3)
7 to 13 d	59 (33.2)	294 (35.4)	180 (44.9)	533 (37.8)
14 to 29 d	20 (11.2)	281 (33.9)	69 (17.2)	370 (26.3)
At least 30 d	29 (16.3)	162 (19.5)	28 (7.0)	219 (15.5)
Missing	4	5	11	20
Total	178 (100.0)	830 (100.0)	401 (100.0)	1409 (100.0)

[a] Missing data are not included in calculations of percentages. Data originate from the Youth Football Surveillance System for youth; National Athletic Treatment, Injury, and Outcomes Network for high school; and National Collegiate Athletic Association Injury Surveillance Program for college, 2012 to 2014 seasons.

concussions (15.5%) resulted in return to play at least 30 days after injury, and 3.1% resulted in return to play less than 24 hours after injury (**Table 4**).

Comparisons Across Levels of Competition

Mean Number of Reported Symptoms

Concussions in high school football had the highest mean (SD) number of reported symptoms (5.60 [3.16]), followed by college (5.56 [3.03]) and youth (4.76 [2.58]) (Table 2). Compared with youth, a higher number of concussion symptoms were reported in high school (β = 1.39; 95% CI, 0.55-2.24). No differences were found between college and youth (β = 0.88; 95% CI, −0.02 to 1.45) and high school and college (β = 0.51; 95% CI, −0.27 to 1.29). No differences were found between competition levels when restricting analyses to migraine symptoms. When restricting analyses to cognitive symptoms, higher mean numbers of symptoms were reported in college athletes (β = 0.42; 95% CI, 0.06-0.78) and high school athletes (β = 0.51; 95% CI, 0.17-0.86) than in youth athletes. High school athletes reported a higher mean number of neurocognitive symptoms than youth (β = 0.14; 95% CI, 0.03-0.25). Higher mean number of sleep symptoms were reported in college athletes (β = 0.23; 95% CI, 0.14-0.31) and high school athletes (β = 0.20; 95% CI, 0.13-0.26) than in youth athletes.

Return-to-Play Time

Distributions of return-to-play time varied by level of competition (Table 4). High school athletes had the highest proportion of concussions with return to play of at least 30 days (19.5%), followed by youth (16.3%) and college athletes (7.0%). In the logistic regression model accounting for clusters by league/team, the odds of return to play of at least 30 days was larger in youth (odds ratio [OR], 2.75; 95% CI, 1.10-6.85) and high school athletes (OR, 2.89; 95% CI 1.61-5.19) than in col-

lege athletes. No difference was found between high school and youth athletes (OR, 1.05; 95% CI, 0.47-2.36).

Youth athletes had the highest proportion of concussions with return to play of less than 24 hours (10.1%), followed by college (4.7%) and high school athletes (0.8%; Table 4). In the logistic regression model accounting for clusters by league/team, the odds of return to play less than 24 hours in youth was larger than that in high school athletes (OR, 6.23; 95% CI, 1.02-37.98). Differences were not found between youth and college athletes (OR, 1.80; 95% CI, 0.39-8.27) and college and high school athletes (OR, 3.47; 95% CI, 0.77-15.67).

Discussion

The Institute of Medicine has called for further research regarding the incidence of concussion in athletes aged 5 to 21 years.[8] Along with incidence research, it is equally important for those managing concussions to understand the symptoms and outcomes among this age group and variations by level of competition. To our knowledge, our study is the first to explore concussion-related symptoms and return-to-play time in youth, high school, and college football athletes. Our findings suggest an association between level of competition and these outcomes and highlight the need for future research to continue exploring how the epidemiology of sports-related concussion varies across the lifespan.

The mean reported number of concussion-related symptoms was lowest in youth football athletes. In particular, youth reported less cognitive and sleep symptoms. Of note, very few concussions across all 3 levels resulted in loss of consciousness, further highlighting the limited utility of that symptom in diagnosing concussion. We caution interpretation of these findings because the understanding of the symptoms may vary by the age of those reporting. Interviews with the athletic trainers evaluating youth football athletes cited unfamiliarity with the youth population as the greatest challenge in assessing concussion, also noting that young children may lack understanding of concussion symptoms.[29] Such challenges may have led to youth athletes reporting symptoms differently from their older counterparts.[29,30] We used parent feedback to better obtain concussion symptoms in their children, although this may have also introduced bias. Although the use of similar symptom checklists across all 3 competition levels increased comparability, future prospective surveillance research should use available child-oriented symptom checklists[30] that were not available during the study timeframe.

High school football athletes reported the highest number of symptoms and the longest return-to-play time. Our results are consistent with many reports of younger athletes taking longer to recover[23,31,32] but also contrast other findings. Covassin et al[33] evaluated 150 high school and 72 collegiate athletes who had sustained a concussion and found no differences by level of play in total number of symptoms reported and the proportion returned to baseline symptom scores by day 14 postinjury.[33] A retrospective study of symptoms in clinical medical records of 184 high school and collegiate athletes found no differences in symptom presence, symptom severity, or return to baseline symptom scores using reliable change index methods.[24] In contrast, Cantu et al[34] examined a specialty clinic sample and found that compared with athletes with concussions younger than 18 years, those aged 18 years and older experienced a greater number and longer duration of symptoms. In contrast, Field et al[22] found that high school football and girls' soccer athletes with concussions had increased postconcussive symptoms relative to control participants on day 5 after injury, whereas college football and women's soccer athletes had no significant differences from control participants by day 5.

There are many possible reasons for the age differences we observed. There may be age differences owing to biological factors, such as puberty and brain development, that occur in youth and high school athletes. Researchers have shown that during adolescence, the brain undergoes a structural reorganization in which white matter increases and gray matter peaks.[25,26] The increase in white matter is typically seen as an increase in axonal myelination.[26] Gray matter has been shown to increase in the brain during childhood but then reaches a peak in adolescence, plateaus, and decreases through adulthood.[25,26] These changes in brain development may result in increases in reported cognitive deficiencies. However, some age differences may be related to organizational differences at each level of competition. High school students have longer durations of class without breaks, which prolong symptom recovery. Additionally, high school students generally have less access to resources regularly available in college programs (eg, medical professionals, neurologists, tutors, and time-management advisors). However, research on how these level-specific variations in resource allocation and setting may be associated with recovery and return to play is lacking, warranting additional research.

Across all 3 levels, a number of athletes with concussions returned to play less than 24 hours after injury. In youth football, 1 in 10 athletes with concussions returned to play less than 24 hours after injury. Such findings may be the result of athletes presenting with delayed concussion symptoms, disagreement between athletic trainers and physicians, or difficulty of youth in reporting symptoms.[30] For example, given no signs of concussion, an athletic trainer must rely on athletes' reporting of symptoms, which may not occur until days after the event. If the athlete participated in any games or practices, the athletic trainer would note the athlete returned in less than 24 hours. At the youth level, procedures required all student athletes to attain physician approval before returning to play, and it is possible the physician disagreed with the athletic trainers' assessment of concussion and provided approval for the student athlete to return the next day. It was not logistically possible to assess athletic trainer–physician agreement. Youth football athletes may also struggle to identify symptoms and express how they feel to athletic trainers, which may result in misdiagnosis that is not corrected until symptoms persist.[30] It is imperative to educate athletic trainers, parents, coaches, and officials on recognition and management of concussions in youth. This should include strategies on how to effectively elicit symptoms in this

younger age group[30] because they may be at greater risk for second impact syndrome.[35]

There were limitations to the study. Our study aimed to examine differences associated with concussion outcomes in 3 levels of competition; however, our study did not evaluate the many organizational, social, environmental, and policy-related factors that may differ at each level of competition. Our study also did not track individual demographics that modify concussion outcomes, such as previous concussions and learning disabilities, which could differ across competition levels. In addition, it is unclear whether individuals with concussions described symptoms or disclosed concussions differently by level of competition. These issues may be more prevalent in younger athletes that are unable to fully comprehend concussion symptoms. Future research that considers these factors is warranted.

The number of athletic trainers varied by level of competition and may contribute to observed variability. Many colleges and universities have more than 1 athletic trainer on staff for football, but most high schools and all youth sites only had 1 athletic trainer, possibly leading to more missed cases than in college football. The samples from all 3 programs are convenience samples, which may limit generalizability to nonparticipating teams and other sports, particularly those with female participants. Given that only 3 seasons of data were examined, it is difficult to ascertain temporal trends; additional seasons of prospective data collection are warranted.

We did not provide a definition of concussion to the athletic trainers reporting injuries, although they were encouraged to use the definition provided by the Consensus Statement on Concussion in Sport.[7] To lessen data collection burden, return to play was a categorical measure, which may result in bias and losses in efficiency compared with data captured as continuous variables. Return to play was also left to the discretion of the clinicians and was therefore not standardized. Rather than examining symptom prevalence across recovery, our measure was an aggregate of symptoms reported at any point during recovery.

Finally, despite comprehensive quality-control procedures, including data entry training, real-time automated range and consistency checks, and human verification, we relied on athletic trainers to enter data into the injury documentation application. Therefore, if a participating athletic trainer chose not to enter data, we could not recover that missing data. However, the percentage of missing data is minimal (<3%) across each level of competition.

Conclusions

Injury surveillance programs are essential in driving the development of evidence-based concussion prevention and policies. To our knowledge, this was the first study to exclusively examine and compare concussion-related symptoms and return-to-play time in youth, high school, and collegiate football athletes. Our study found that the mean reported number of concussion-related symptoms was higher in high school and collegiate athletes than in youth athletes. Collegiate football athletes also reported a higher mean number of cognitive symptoms compared with youth athletes, demonstrating differences in concussion symptoms between levels of competition. Also, very few concussions resulted in loss of consciousness, further highlighting the limited utility of that symptom in diagnosing concussion. These data provide the most common symptoms across levels of play, providing clinicians some guidance as to which symptoms should be minimally included in an assessment. High school athletes had the highest proportion of concussions with a long return-to-play time. Given that our study did not measure individual characteristics, as well as the many level-specific organizational, social-environmental, and policy-related factors, further research is warranted to validate our findings.

ARTICLE INFORMATION

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Study concept and design: Kerr, Djoko, Dompier.
Acquisition, analysis, or interpretation of data: All authors.
Drafting of the manuscript: Kerr, Zuckerman, Djoko.
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REFERENCES

1. National Collegiate Athletic Association. Student-athlete participation: 1981-82 to 2012-13. 2014; http://www.ncaapublications.com/productdownloads/PR2014.pdf. Accessed September 10, 2014.

2. National Federation of State High School Associations. Participation statistics. http://www.nfhs.org/ParticipationStatics/ParticipationStatics.aspx/. Published 2014. Accessed September 10, 2014.

3. National Council of Youth Sports. Reports on trends and participation in organized youth sports. 2008; http://www.ncys.org/pdfs/2008/2008-ncys-market-research-report.pdf. Accessed September 10, 2014.

4. Bailey R. Physical education and sport in schools: a review of benefits and outcomes. *J Sch Health*. 2006;76(8):397-401.

5. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury: a brief overview. *J Head Trauma Rehabil*. 2006;21(5):375-378.

6. Giza CC, Kutcher JS, Ashwal S, et al. Summary of evidence-based guideline update: evaluation and management of concussion in sports: report of the Guideline Development Subcommittee of the American Academy of Neurology. *Neurology*. 2013;80(24):2250-2257.

7. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *Br J Sports Med*. 2013;47(5):250-258.

8. Institute of Medicine. Sports-related concussions in youth: improving the science, changing the culture. http://www.iom.edu/~/media/Files/Report%20Files/2013/Concussions/concussions-RB.pdf. Published 2013. Accessed September 10, 2014.

9. Wasserman EB, Kerr ZY, Zuckerman SL, Covassin T. Epidemiology of sports-related concussions in National Collegiate Athletic Association athletes from 2009-2010 to 2013-2014: symptom prevalence, symptom resolution time, and return-to-play time. *Am J Sports Med*. 2016;44(1):226-233.

10. Zuckerman SL, Kerr ZY, Yengo-Kahn A, Wasserman E, Covassin T, Solomon GS. Epidemiology of sports-related concussion in NCAA athletes from 2009-2010 to 2013-2014: incidence, recurrence, and mechanisms. *Am J Sports Med*. 2015;43(11):2654-2662.

11. Gessel LM, Fields SK, Collins CL, Dick RW, Comstock RD. Concussions among United States high school and collegiate athletes. *J Athl Train*. 2007;42(4):495-503.

12. Marar M, McIlvain NM, Fields SK, Comstock RD. Epidemiology of concussions among United States high school athletes in 20 sports. *Am J Sports Med*. 2012;40(4):747-755.

13. Pfister T, Pfister K, Hagel B, Ghali WA, Ronksley PE. The incidence of concussion in youth sports: a systematic review and meta-analysis. *Br J Sports Med*. 2016;50(5):292-297.

14. Dompier TP, Kerr ZY, Marshall SW, et al. Incidence of concussion during practice and games in youth, high school, and collegiate American football players. *JAMA Pediatr*. 2015;169(7):659-665.

15. Piland SG, Motl RW, Ferrara MS, Peterson CL. Evidence for the factorial and construct validity of a self-report concussion symptoms scale. *J Athl Train*. 2003;38(2):104-112.

16. Iverson GL, Lange RT. Examination of "postconcussion-like" symptoms in a healthy sample. *Appl Neuropsychol*. 2003;10(3):137-144.

17. Makdissi M, Darby D, Maruff P, Ugoni A, Brukner P, McCrory PR. Natural history of concussion in sport: markers of severity and implications for management. *Am J Sports Med*. 2010;38(3):464-471.

18. Erlanger D, Kaushik T, Cantu R, et al. Symptom-based assessment of the severity of a concussion. *J Neurosurg*. 2003;98(3):477-484.

19. Guskiewicz KM, McCrea M, Marshall SW, et al. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. *JAMA*. 2003;290(19):2549-2555.

20. Lau BC, Kontos AP, Collins MW, Mucha A, Lovell MR. Which on-field signs/symptoms predict protracted recovery from sport-related concussion among high school football players? *Am J Sports Med*. 2011;39(11):2311-2318.

21. Guskiewicz KM, Weaver NL, Padua DA, Garrett WE Jr. Epidemiology of concussion in collegiate and high school football players. *Am J Sports Med*. 2000;28(5):643-650.

22. Field M, Collins MW, Lovell MR, Maroon J. Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. *J Pediatr*. 2003;142(5):546-553.

23. Zuckerman SL, Lee YM, Odom MJ, Solomon GS, Forbes JA, Sills AK. Recovery from sports-related concussion: days to return to neurocognitive baseline in adolescents versus young adults. *Surg Neurol Int*. 2012;3:130. doi:10.4103/2152-7806.102945.

24. Lee YM, Odom MJ, Zuckerman SL, Solomon GS, Sills AK. Does age affect symptom recovery after sports-related concussion? a study of high school and college athletes. *J Neurosurg Pediatr*. 2013;12(6):537-544.

25. Blakemore SJ, Burnett S, Dahl RE. The role of puberty in the developing adolescent brain. *Hum Brain Mapp*. 2010;31(6):926-933.

26. Blakemore SJ, Choudhury S. Development of the adolescent brain: implications for executive function and social cognition. *J Child Psychol Psychiatry*. 2006;47(3-4):296-312.

27. Dompier TP, Marshall SW, Kerr ZY, Hayden R. The National Athletic Treatment, Injury and Outcomes Network (NATION): methods of the surveillance program, 2011-2012 through 2013-2014. *J Athl Train*. 2015;50(8):862-869.

28. Kerr ZY, Dompier TP, Snook EM, et al. National Collegiate Athletic Association Injury Surveillance system: review of methods for 2004-2005 through 2013-2014 data collection. *J Athl Train*. 2014;49(4):552-560.

29. Murphy J. Challenges and recommendations for the assessment of concussion in youth football players. Paper presented at: National Athletic Trainers' Association 65th Clinical Symposia and AT Expo; June 26, 2014; Indianapolis, IN.

30. Sady MD, Vaughan CG, Gioia GA. Psychometric characteristics of the postconcussion symptom inventory in children and adolescents. *Arch Clin Neuropsychol*. 2014;29(4):348-363.

31. Foley C, Gregory A, Solomon G. Young age as a modifying factor in sports concussion management: what is the evidence? *Curr Sports Med Rep*. 2014;13(6):390-394.

32. Williams RM, Puetz TW, Giza CC, Broglio SP. Concussion recovery time among high school and collegiate athletes: a systematic review and meta-analysis. *Sports Med*. 2015;45(6):893-903.

33. Covassin T, Elbin RJ, Harris W, Parker T, Kontos A. The role of age and sex in symptoms, neurocognitive performance, and postural stability in athletes after concussion. *Am J Sports Med*. 2012;40(6):1303-1312.

34. Cantu RC, Guskiewicz K, Register-Mihalik JK. A retrospective clinical analysis of moderate to severe athletic concussions. *PM R*. 2010;2(12):1088-1093.

35. McCrory P, Davis G, Makdissi M. Second impact syndrome or cerebral swelling after sporting head injury. *Curr Sports Med Rep*. 2012;11(1):21-23.